UCRL-JRNL-213397

Octupole and hexadecapole bands in 152Sm

P. E. Garrett, W. D. Kulp, J. L. Wood, D. Bandyopadhyay, S. Christen, S. Choudry, A. Dewald, A. Fitzler, C. Fransen, K. Jessen, J. Jolie, A. Kloezer, P. Kudejova, A. Kumar, S. R. Lesher, A. Linnemann, A. Lisetskiy, D. Martin, M. Masur, M. T. McEllistrem, O. Moller, M. Mynk, J. N. Orce, P. Pejovic, T. Pissulla, J.-M. Regis, A. Schiller, D. Tonev, S. W. Yates

July 5, 2005

Journal of Physics G

Disclaimer

Octupole and hexadecapole bands in ^{152}Sm

P.E. Garrett[†,‡,§], W.D. Kulp[||], J.L. Wood[||], D. Bandyopadhyay[¶], S. Christen[+], S. Choudry[¶], A. Dewald[+], A. Fitzler[+], C. Fransen[+], K. Jessen[+], J. Jolie[+], A. Kloezer[+], P. Kudejova[+], A. Kumar[¶], S.R. Lesher[¶], A. Linnemann[+], A. Lisetskiy[+], D. Martin[+], M. Masur[+], M.T. McEllistrem[¶], O. Möller[+], M. Mynk[¶], J.N. Orce[¶], P. Pejovic[+], T. Pissulla[+], J.-M. Regis[+], A. Schiller[§], D. Tonev[+], S.W. Yates[¶]

† Dept. of Physics, University of Guelph, Guelph, Ontario, Canada
‡ TRIUMF, 4004 Wesbrook Mall, Vancouver, British Columbia, Canada
§ Lawrence Livermore National Laboratory, Livermore, California, USA
|| Dept. of Physics, Georgia Institute of Technology, Atlanta, Georgia, USA
+ Institut für Kernphysik, Universtät zu Köln, Köln, Germany
¶ University of Kentucky, Lexington, Kentucky, USA

Abstract. The nucleus ^{152}Sm is characterized by a variety of low-energy collective modes, conventionally described as rotations, β vibrations, and γ vibrations. Recently, it has been suggested that ^{152}Sm is at a critical point between spherical and deformed collective phases. Consequently, ^{152}Sm is being studied by a variety of techniques, including radioactive decay, multi-step Coulomb excitation, in-beam $(\alpha, 2n\gamma)$ γ-ray spectroscopy, and $(n, n'\gamma)$ spectroscopy. The present work focuses on the latter two reactions; these have been used to investigate the low-lying bands associated with the octupole degree of freedom, including one built on the first excited 0^+ band. In addition, the $K^\pi = 4^+$ hexadecapole vibrational band has been identified.

E-mail: pgarrett@physics.uoguelph.ca

1. Introduction

The $N = 90$ shape transition region has long been of interest due to the rapid evolution of structure that occurs in spanning the nuclei from $N = 88$ to $N = 92$. Nuclei with $N \leq 88$ have level schemes that resemble those expected for "spherical" vibrational nuclei, whereas those for $N \geq 92$ resemble well-deformed prolate rotors. The $N = 90$ nuclei, especially ^{150}Nd, ^{152}Sm, and ^{154}Gd, lie at the centre of the transition between these two shapes, and a series [1–10] of two-neutron-transfer reactions provided strong evidence for shape coexistence, with excited "spherical" structures coexisting with more-deformed ground states. This picture changed little for more than 30 years until it was suggested [11] that the 0_2^+ state in ^{152}Sm was a spherical state, with multiphonon structures being built upon it, and this was an example of a "phase" coexistence [12–15], The phase coexistence picture differs from the idea of shape coexistence arising from intruder orbitals in that it depends on a critical value of a control parameter related to ϵ/κ, the parameters for the Casimir operators $C_1(\mathrm{U5})$ and $C_2(\mathrm{SU3})$ [12–15] in the IBM. Building on this idea, Iachello [16] developed an analytical solution for the

Bohr Hamiltonian assuming a square-well potential in β, believed to approximate the phase-coexistence potential, and the $N = 90$ isotones, ^{150}Nd and ^{152}Sm in particular, were cited [17] as the first empirical examples of this new critical point solution, dubbed $X(5)$. Other examples of $X(5)$ were soon suggested (see, for example, Refs. [18–20]). It has been pointed out [21, 22], however, that other descriptions of the shape transitional region appear to compare to the known experimental data just as well, if not better than, the $X(5)$ model.

It has been highlighted, especially by Burke [21], that current data does not distinguish between different competing models for the structure of ^{152}Sm. The need to perform thorough tests of the predictions of the phase-coexistence $X(5)$ model is clear, as this would have a profound impact on our understanding of nuclear collectivity. With this in mind, a far-reaching programme of detailed spectroscopy into the $N = 90$ isotones has been undertaken. This programme involves the use of a variety of techniques, including both in-beam and decay measurements, to perform detailed spectroscopy of non-yrast states. The experiments performed on ^{152}Sm to date include ^{152}Eu decay [23] using the 8π spectrometer at Lawrence Berkeley National Laboratory (LBNL), multiple Coulomb excitation [24] of a ^{152}Sm beam on a ^{208}Pb target using CHICO and GAMMASPHERE at LBNL, decay of ^{152}Pm at the Studsvik Research Reactor, a ^{150}Nd$(\alpha, 2n\gamma)$ reaction using the HORUS spectrometer at the University of Cologne, and the ^{152}Sm$(n, n'\gamma)$ reaction at the University of Kentucky. In the present work, some preliminary findings from the latter two in-beam experiments are described.

2. Experimental details

Fusion-evaporation reactions are powerful spectroscopic tools in that they are compound nuclear reactions, and hence levels are populated in a statistical manner with no sensitivity to their structure. Levels can be populated with large values of angular momentum. In the case of ^{152}Sm, however, there are very few stable beam-target combinations that can be used. Of the possible reactions, the ^{150}Nd$(\alpha, 2n\gamma)$ reaction was chosen for its ability to populate non-yrast states [25], and the fact that it brings in a moderate amount of angular momentum. In one of the first experiments with the new HORUS spectrometer at the Cologne tandem accelerator facility, beams of several pnA of 22.5 MeV α particles bombarded targets of ^{150}Nd. The HORUS spectrometer consisted of 1 EUROBALL cluster detector and 9 conventional coaxial detectors mounted in a cube-like arrangement surrounding the target position. Approximately 2×10^9 $\gamma\gamma$-coincidence events were recorded, of which 1×10^9 were sorted into a $\gamma\gamma$ matrix (events in adjacent germanium crystals of the cluster detector accounted for approximately $\frac{1}{2}$ of all events). To complement the data at intermediate spin obtained from the $(\alpha, 2n\gamma)$ reaction, the $(n, n'\gamma)$ reaction was chosen. It also offers comprehensive population up to $\approx 6\hbar$, and level lifetimes can be extracted with a Doppler-shift attenuation method analysis. A series of experiments, including excitation functions, angular distributions, and $\gamma\gamma$ coincidences, was performed at the University of Kentucky accelerator facility.

3. Results and discussion

Figure 1 is a partial level scheme that shows the $K = 4^+$ hexadecapole band that was established from results of $\gamma\gamma$ coincidences following the $(\alpha, 2n)$ reaction. The spin of the band head was assigned from the $(n, n'\gamma)$ data. The assignment of hexadecapole character is based on the known systematics of $K = 4^+$ bands in the region [26], and its population in single-nucleon transfer work [27]. Its observation at only 1.6 times the γ-band energy implies that the hexadecapole degree of freedom is important for low-lying levels in ^{152}Sm, as was indicated by the large $B(E4; 4_1^+ \rightarrow 0_{gs}^+)$ value [28].

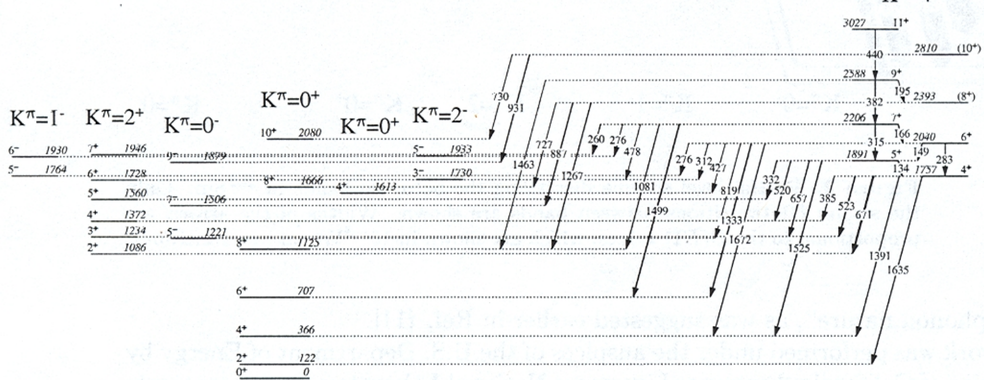

Figure 1. Results from analysis of the ^{150}Nd$(\alpha, 2n\gamma\gamma)$ coincidence relations establishing a $K^\pi = 4^+$ band at 1757 keV in ^{152}Sm. For K^π assignments, see Fig. 2 and (for the 1613 state) Ref. [29].

The octupole bands with $K^\pi = 0^-$ (at 963 keV), $K^\pi = 1^-$ (at 1510 keV), and $K^\pi = 2^-$ (at 1650 keV) were observed up to relatively high spin in the $(\alpha, 2n)$ data. At low-spins, level lifetimes had been established from a previous $(n, n'\gamma)$ study [30] and in the present work. Some of the $B(E1)$ values (in 10^{-3} Wu) for decay from the known $K^\pi = 0^-$ and $K^\pi = 1^-$ bands are shown in Fig. 2. Of note are the large $B(E1; K^\pi = 0^- \rightarrow \text{gsb})$ values, of 4–8 10^{-3}Wu, compared to other known $E1$ transitions in this nucleus (for example, decay from the $K^\pi = 1^-$ states). Moreover, a series of levels, beginning with the 1^- level at 1681 keV, a 3^- level at 1779 keV, and a tentative 5^- level at 1976, have an energy spacing and decay pattern to the first $K^\pi = 0^+$ band strongly similar to the first $K^\pi = 0^-$ band and its decay to the ground state band. The expected energy for an octupole excitation built on the first $K^\pi = 0^+$ band of 685+963=1648 keV matches well the observed energy of 1681 keV. The extracted $B(E1; K^\pi = 0^- \rightarrow K^\pi = 0_2^+)$ values for the 1^- and 3^- levels of 2–5 10^{-3}Wu also strongly favour its identification as an octupole excitation built on the 685-keV $K^\pi = 0_2^+$ band. This implies that the octupole degrees of freedom are also playing a significant role in the low-lying structure of ^{152}Sm.

4. Conclusions

The $K^\pi = 4^+$ hexadecapole band has been observed at 1757 keV, fitting well the systematics of hexadecapole bands in this mass region. The octupole bands have been investigated, and the $K^\pi = 0^-$ state built on the $K^\pi = 0_2^+$ level is suggested. More details will be published in Ref. [31], and the implications on the shape/phase coexistence models are currently being studied. However, the appearence of the second $K^\pi = 0^-$ band would seem to imply that the 0^+ state at 684 keV does not have a

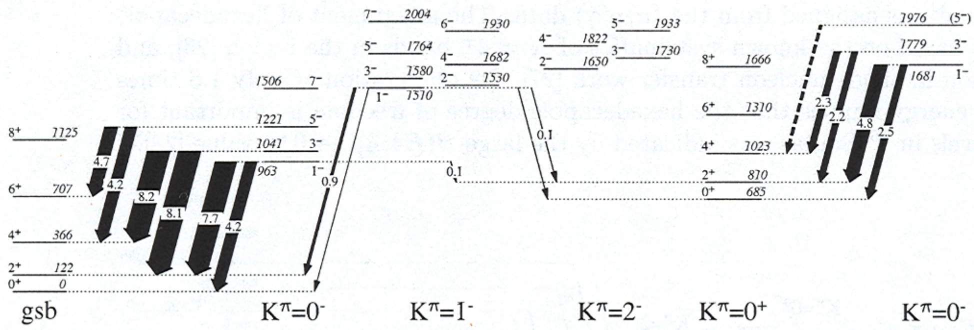

Figure 2. Partial level scheme displaying the octupole bands in ^{152}Sm. Only the strong $E1$ transitions between bands are shown. Widths of the arrows are proportional to the $B(E1)$ values, which are shown in 10^{-3}Wu on the transitions.

"spherical-phonon nature", as was suggested earlier in Ref. [11].

This work was performed under the auspices of the U.S. Department of Energy by the University of California, Lawrence Livermore National Laboratory under contracts no. W-7405-ENG-48.

References

[1] S. Hinds, J.H. Bjerregaard, O. Hansen, and O. Nathan, Phys. Lett. **14**, 48 (1965).
[2] J.H. Bjerregaard, O. Hansen, P. Nathan, and S. Hinds, Nucl. Phys. **86**, 146 (1966).
[3] W. McLatchie, J.E. Kitching, and W. Darcey, Phys. Lett. **30B**, 529 (1969).
[4] R. Chapman, W. McLatchie and J.E. Kitching, Phys. Lett. **31B**, 292 (1971).
[5] R. Chapman, W. McLatchie and J.E. Kitching, Nucl. Phys. **A186**, 603 (1972).
[6] P. Debenham and N.M. Hintz, Nucl. Phys. **A195**, 385 (1972).
[7] D.G. Fleming, C. Günther, G.B. Hagemann, B. Herskind, and P.O. Tjøm, Phys. Rev. Lett **27**, 1235 (1971).
[8] Th.W. Elze, J.S. Boyno, and J.R. Huizenga, Nucl. Phys. **A187**, 473 (1972).
[9] W. Oelert, G. Lindström, and V. Riech, Nucl. Phys. **A233**, 237 (1974).
[10] M.A.M. Shahbuddin, D.G. Burke, I. Nowikow, and J.C. Waddington, Nucl. Phys. **A340**, 109 (1980).
[11] R.F. Casten, M. Wilhelm, E. Radermacher, N.V. Zamfir, and P. von Brentano, Phys. Rev. C **57**, R1553 (1998).
[12] F. Iachello, N.V. Zamfir, and R.F. Casten, Phys. Rev. Lett. **81**, 1191 (1998).
[13] N.V. Zamfir *et al.*, Phys. Rev. C **60**, 054312 (1999).
[14] R.F. Casten, D. Kusnezov, and N.V. Zamfir, Phys. Rev. Lett. **82**, 5000 (1999).
[15] Jing-ye Zhang, M.A. Caprio, N.V. Zamfir, and R.F. Casten, Phys. Rev. C **60**, 061303 (1999).
[16] F. Iachello, Phys. Rev. Lett. **87**, 052502 (2001).
[17] R.F. Casten and N.V. Zamfir, Phys. Rev. Lett. **87**, 052503 (2001).
[18] R.M. Clark *et al.*, Phys. Rev. C **68**, 037301 (2003).
[19] E.A. McCutchan *et al.*, Phys. Rev. C **69**, 024308 (2004).
[20] E.A. McCutchan *et al.*, Phys. Rev. C **71**, 024309 (2005).
[21] D.G. Burke, Phys. Rev. C **66**, 024312 (2002).
[22] R.M. Clark *et al.*, Phys. Rev. C **67**, 041302 (2003).
[23] J. L. Wood *et al.*, Bull. Am. Phys. Soc. **47**, no. 6, p. 81 (2002).
[24] W. D. Kulp *et al.*, Bull. Am. Phys. Soc. **47**, no. 6, p. 93, (2002); ibid. **48** no. 8, p. 70 (2003).
[25] J. Kern, Phys. Lett. **B320**, 7 (1994).
[26] D.G. Burke, Phys. Rev. Lett. **73**, 1899 (1994).
[27] C.R. Hirning and D.G. Burke, Can. J. Phys. **55**, 1137 (1977).
[28] R.K. Sheline, B. Singh, P.C. Sood, and S.Y. Chu, Czech. J. Phys. **49**, 1047 (1999).
[29] W.D. Kulp *et al.*, Phys. Rev. C *submitted* (2005).
[30] A. Jungclaus *et al.*, Phys. Rev. C **48**, 1005 (1993).

[31] P.E. Garrett *et al.*, to be published.